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Tunable UV Filters

Contract Report Contract NASW-5007

Principal Investigator
Marilyn E. Bruner

Co-Investigator
William A Rosenberg

Period of Performance:

1 January, 1996 through 31 October, 1996

11 November, 1996

*Lockheed Martin Advanced Technology Center
Palo Alto, California*

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1 Introduction

The objective of this contract is to investigate the feasibility of making Fabry-Perot etalons that will function at wavelengths below 155 nm. There are three main parts to the study as follows: a theoretical design study of reflective coatings for etalon plates, fabrication and testing of coatings for the most promising designs and finally, evaluation of the best designs in an etalon test fixture. The expected benefit to the NASA Solar Physics program is the future capability to make wide-field high resolution diagnostic images such as spectroheliograms, dopplergrams, and density maps in isolated spectral lines formed in the upper chromosphere, transition region and lower corona. These observations will be relevant to the Mechanisms of Solar Variability (MSV) and Solar B programs to studies of solar flares, and to the study of coronal heating mechanisms. Work during this period of performance included a survey of recent literature, substantial progress on the theoretical study and initial work on coating preparation. Progress on the investigation has been greatly assisted by Dr. Muamer Zukic of Cascade Optical Coatings, Inc. who has developed computer codes and databases that are relevant to the problem. One paper was prepared and presented at the August, 1996 International Symposium on Optical Science, Engineering, and Instrumentation in Denver, Colo. A pre-print of this paper is included as Appendix A.

2 Approach

A Fabry-Perot etalon consists of two parallel reflecting surfaces separated by a small gap (typically a few wavelengths of the light to be analyzed). The development of a successful etalon requires two elements: transparent substrates or spacers of adequate flatness and efficient, high reflectivity coatings. We have considered only vacuum-spaced etalons in order to maximize the range of refractive indices available for the reflector design.

In the vacuum ultraviolet, the design of reflecting coatings is severely limited by the properties of materials. Most materials are opaque except in very thin layers, and the available range of refractive indices is small. The most useful materials tend to be fluoride salts of alkali metals and rare earths such as LiF, MgF₂, BaF₂, LaF₃, etc. Some metals, such as aluminum, have high reflectivity, but their strong absorption coefficients make them difficult to use as an effective etalon coating.

We have chosen to pursue all-dielectric multilayer coatings for this phase of our investigation, based partly on work carried out at the University of Alabama, Huntsville Dr. M. Zukic and colleagues [1], [2], [3]. The coatings consist of alternating layers of high-index and low-index materials whose optical thicknesses are chosen to produce constructive interference in the reflected beam. Both BaF₂ and LaF₃ are suitable as high-index materials, though both have relatively high absorption coefficients. MgF₂ works well as the low-index material and transmits well down to about 115 nm.

In the simplest case, the optical thickness of each layer is $1/4$ wave, so that all partially reflected beams are in phase. However, as shown by Zukic and Torr [4], the total reflectivity of the multilayer stack may be improved by decreasing the relative thickness of each high-index layer with respect to the low-index one, keeping the optical thickness of each pair at $1/2$ wave. Zukic and Torr have applied the name “ π stack” to this design. The resulting coating will reflect strongly at and near the design wavelength. The peak reflectivity of a π stack can be larger than the equivalent $1/4$ wave design because of the lower optical path length in the (more strongly absorbing) high-index material. This optimization also minimizes the absorptance at the design wavelength so that the residual energy is transmitted to the substrate; an important characteristic for Fabry-Perot applications.

At wavelengths outside of the main reflection peak, most of the incident energy is either absorbed or transmitted to the substrate. Increasing the number of periods increases the peak reflectivity and decreases the usable bandwidth. It is also possible to create coatings with two or more reflection peaks by varying the layer period through the coating.

3 Theoretical Study

We have been greatly assisted in this portion of the investigation by the participation of Dr. Zukic, who was able to use his existing computer codes and databases to prepare several candidate reflector designs and predict their performance. Single-band, two-band and three-band coatings have been designed for wavelengths ranging from 121.1 nm to 155 nm. All designs are based on alternating layers of magnesium and lanthanum fluorides on a magnesium fluoride substrate. The results are very encouraging. The finesse for a single-band etalon can be as high as 34 at 155 nm and it appears that functional etalons may be

Wavelength (nm)	Predicted Finesse	Maximum Transmission
121	4.9	4.74 %
130	5.8	2.84 %
135	6.4	8.38 %
145	14.7	39.1 %
155	34.2	36.5 %

Table 1: Initial results from a theoretical study of Fabry-Perot etalon performance.

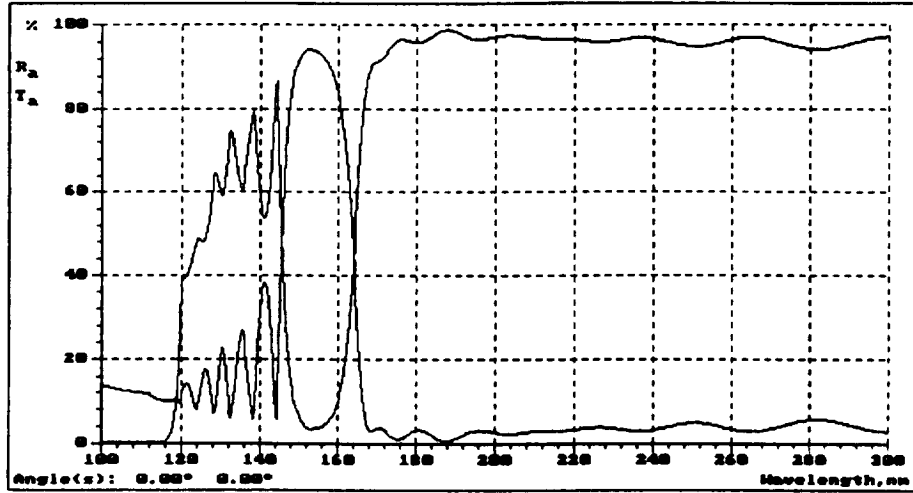


Figure 1: Reflectance, transmittance and absorptance of a multilayer optimized for use in a Fabry-Perot etalon operating in the 155 nm range. At the design wavelength, the multilayer has a peak reflectance of 91.2%, a transmittance of 5.3% and an absorptance of 3.5%.

made for wavelengths as short as 121 nm. Figure 1 shows the optical properties of the 155 nm coating; its predicted performance in an etalon is shown in Figure 2. Predictions for the 145 nm design are given in the paper of Appendix A. A summary of these results is given in Table 1.

Figure 3 shows a two band coating designed to operate at 140 and 155 nm, achieving 86% and 90%, respectively, at the two wavelengths. An etalon based on this coating would be useful for diagnostic spectroscopy of the solar transition region. The resonance doublet of C IV (154,8 and 155.0 nm) would be observed in the long wavelength band; the resonance lines of Si IV and the density sensitive lines of O IV and S IV all lie in the short wavelength band. An example of a three-band coating design is given in Figure 4.

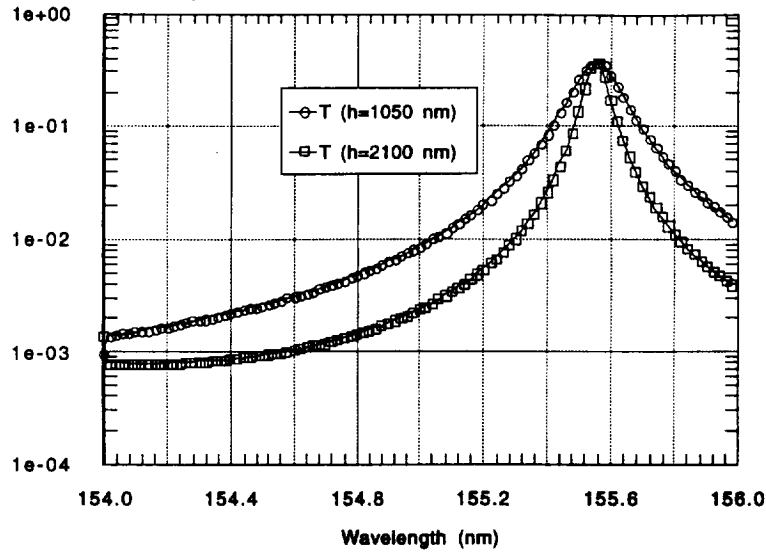


Figure 2: Predicted performance of a Fabry-Perot etalon using the multilayer coatings designed for 155 nm. The two curves correspond to different vacuum gap thicknesses, as shown on the plot. A finesse of 34.2 and a maximum transmission of 36.5% are realized in each case.

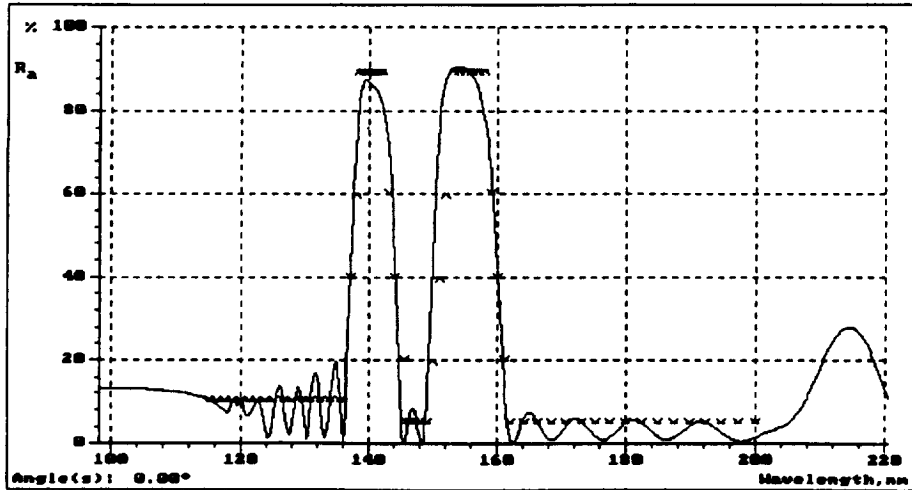


Figure 3: Multilayer dielectric coating designed to cover two spectral ranges. Such coatings would be useful for observing sets of spectral lines whose wavelength separations are too large to fit within a single range. This coating was designed for observing the solar transition region in the C IV, Si IV, O IV and S IV lines.

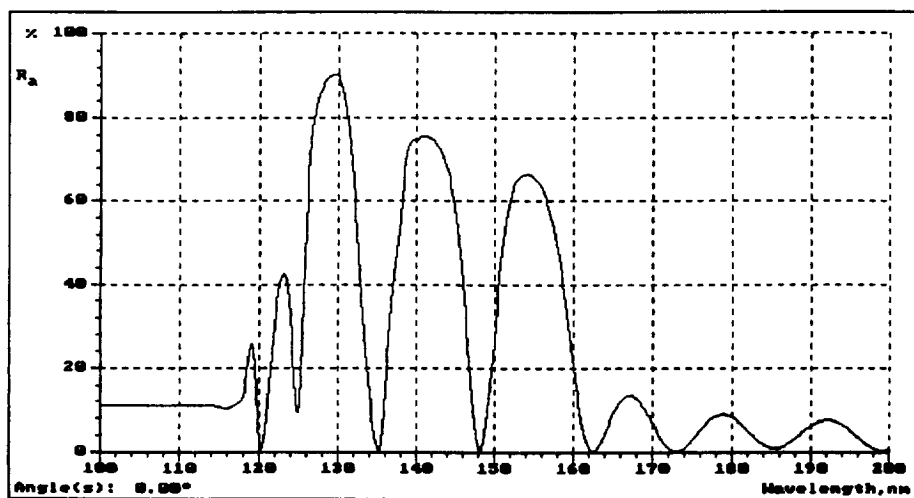


Figure 4: Multilayer dielectric coating designed to cover three spectral ranges.

4 Coating Tests

Dr Zukic also assisted in the second phase of the investigation, though some delay was encountered due to his relocation from the University of Alabama, Huntsville to Cascade Optical Coatings Inc. To date, one set of test coatings has been made at Cascade under Zukic's direction. Since his previous work had been carried out at a different institution, these first coatings were primarily intended to provide a calibration of the Cascade equipment. Materials used were alternating layers of MgF_2 and LaF_3 and the substrate material was Pyrex. Four samples, placed at varying distances from the evaporation source, were coated simultaneously. The distances were chosen such that the expected range of periods would include the 155 nm design wavelength.

Layer thicknesses for the first coating run were monitored by an optical system operating at visible wavelengths, as this equipment was already set up and available at Cascade. However, it proved to be too insensitive to provide adequate thickness control for the ultraviolet coatings. A quartz crystal microbalance will be used for subsequent coating runs planned for later this calendar year.

4.1 Measurements

Reflectivity measurements were carried out in a reflectometer chamber at our laboratory in Palo Alto. An Acton Research Corp. deuterium lamp and a glancing incidence monochromator provided illumination in the 120 to 180 nm spectral range. The detector was an EMR 541F photomultiplier operating in the pulse counting mode. Samples were mounted on a motor-driven rotary stage. The detector was mounted on a second drive that was arranged such that it tracked the reflected beam as the incidence angle was varied. The dark count rate from the EMR 541F detector was below 1 count/sec so that background corrections were negligible. The entire optical path was evacuated to below 10^{-6} torr.

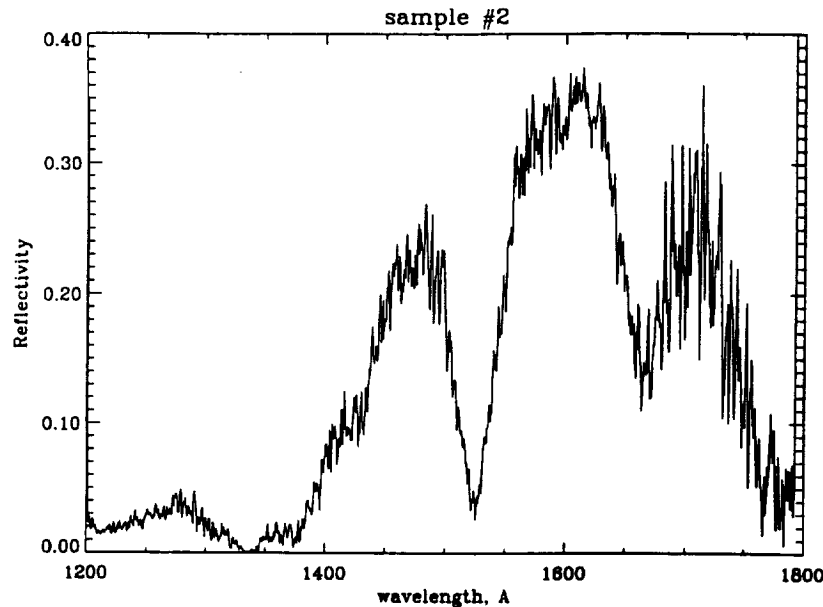


Figure 5: Test results from the first coater calibration run at Cascade Optical Coatings, Inc. The broad wavelength response of the coating has been attributed to the use of an inappropriate thickness monitoring method.

Wavelength scanning and data logging were controlled by a personal computer with appropriate interfaces. Alternate scans were made of the incident and reflected beams and the reflectivity curves were derived from their ratios. The lamp was sufficiently stable that more frequent sampling of the incident beam was not necessary. All measurements were made with a 5 degree angle of incidence; the smallest permitted by the size of the detector package.

Results from this first measurement run revealed the limitations of the thickness monitoring equipment. Instead of a single narrow band of high reflectivity, we found substantially lower values spread out over a much larger wavelength range, as shown in Figure 5. The maximum reflectivity was around 35 % in the region of 160 nm.

5 Discussion

The theoretical work discussed in Section 3 has demonstrated the existence of class of design solutions for the reflector coatings required to make an ultraviolet etalon. Etalons based on π -stack multilayers using LaF_3 and MgF_2 should work well down to about 130 nm, and can work at 121 nm with a finesse approaching 5. Moreover, the low absorptance of the π -stack design appears to allow one to make etalons that perform well in two or more wavelength ranges, enhancing their utility. These results have substantially exceeded our expectations for the program.

Although we were disappointed by the test results on the initial coatings made at Cascade Optical Coatings, Inc., the problem appears to be understood. Subsequent coatings will be done using a quartz crystal microbalance to control layer thickness. The present results are not indicative of the potential performance of the designs. The reflectivities of coatings made

by Dr. Zukic in his former laboratory were in substantial agreement with the theory.

6 Future Plans

Work planned for the next reporting period will include continuation of the test coating program, beginning with the 155.0 nm design and proceeding to shorter wavelengths. We expect the results from the next coating run to be available in early December, 1996. Once the coater calibration is complete, test samples will be prepared on MgF_2 substrates so that the transmission curves may also be measured. During the first quarter in calendar year 1997, we plan to begin design work on the laboratory test fixture to be used for etalon testing.

References

- [1] M. Zukic, D. G. Torr, J. F. Spann and M. R. Torr, *Applied Optics*, **29**, 4284-4292, (1990).
- [2] M. Zukic, D. G. Torr, J. F. Spann and M. R. Torr, *Applied Optics*, **29**, 4293-4302, (1990).
- [3] M. Zukic and D. G. Torr, *Thin Films for Optical Coatings* (CRC Press, Inc., Boca Raton, Fl., 1995), 79-104.
- [4] M. Zukic and D. B. Torr, *Applied Optics*, **31**, 1588-1596, (1992).

A Papers

High Resolution Spectral Imaging of the Sun in the Far Ultraviolet

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Abstract

The Transition Region and Coronal Explorer instrument (TRACE) will use narrow-band interference filters together with other appropriate band limiting elements to make high resolution images of the Sun in the C IV lines at 154.8 and 155.0 nm. Filter observations of solar C IV emission are complicated by the presence of UV Continuum and nearby chromospheric lines because of the relatively wide bandpasses of the narrowest currently available interference filters. TRACE will use a series of filters to estimate the effects of the UV continuum and the long-wavelength "leaks" in the blocking filters which we show are the most important contaminants in the C IV images. Further improvements in filtergraph performance may be realized through the use of tunable Fabry-Perot etalons, which have been under development at Lockheed-Martin. We present test data from a cultured quartz etalon designed for 155 nm, and will discuss the prospects for etalons operating at substantially shorter wavelengths.

1 Introduction

TRACE is a NASA sponsored Small Explorer mission designed to study the sun by means of high resolution imaging in the UV and EUV regions of the spectrum. Its principal instrument is a cassegrain telescope of 30 cm diameter and 8.66 m effective focal length whose aperture is divided into quadrants. Three of these quadrants carry multilayer coatings that reflect strongly in narrow bands centered on selected EUV spectral lines. The fourth quadrant is dedicated to the observation of the strong resonance lines of hydrogen at 1216 Å, C IV at 1548 and 1550 Å and the continuum near 1600 Å. Interference filters are used to select among these wavelengths. A lumigen-coated CCD camera serves as the detector. More complete descriptions of the TRACE instrument have been given by Strong et al. (1994) and in a paper by Tarbell et al. (1996), presented at this conference. The remainder of this paper will concentrate on problems that are peculiar to the C IV lines, which must be observed in the presence of a strong continuum and nearby spectral lines that are formed in other temperature regions.

In Section 2 we briefly review the general features of the UV solar spectrum. Section 3 presents the observing strategy employed by TRACE, in which we use several different filters to evaluate and correct for the major contaminants to the 1550 Å filtergrams.

In Section 4, we discuss the use of Fabry Perot etalons to gain better isolation of the C IV lines and to observe other astrophysically important lines in the 1200 – 1600 Å wavelength range.

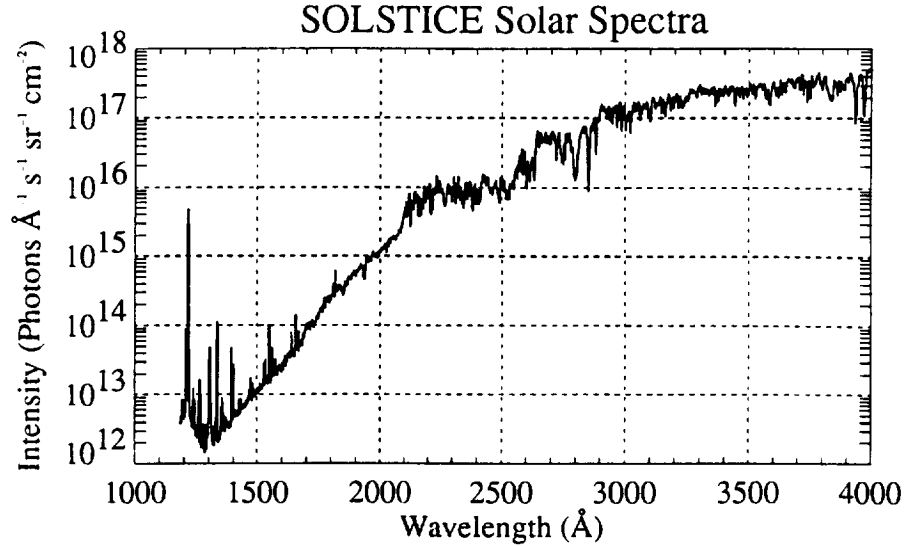


Figure 1: Solar Ultraviolet Spectrum, recorded by the SOLSTICE experiment on the UARS spacecraft.

2 The Solar UV Spectrum

Observations of the solar UV spectrum began in the 1950's with the pioneering work done at the University of Colorado under W.A. Rense, at the Air Force Cambridge Research Laboratory under H. Hinteregger, and at the Naval Research Laboratory under R. Tousey. The early NRL work was especially noteworthy, as it provided the most comprehensive spectral atlas and revealed the general properties of the spectrum (e.g. Tousey, 1963). Subsequent observations of the spectrum have been made by many workers from a variety of space platforms including sounding rockets, the Skylab, OSO-5, OSO-8, SMM, Spacelab 2, UARS, SOHO and other space observatories. A comprehensive review of the data is well beyond the scope of this paper.

The main features of the average solar spectrum are illustrated in Figure 1, which was produced by the SOLSTICE instrument (Rottman, 1996) on the UARS spacecraft. We have used the SOLSTICE data throughout this study in preference to the higher resolution spectra from the HRTS or UVSP instruments, both because of the broader wavelength coverage of the former and because they appear to be less affected by instrument calibration and / or stray light. The dominant feature of the spectrum is a continuum that increases by about five orders of magnitude between 1200 and 4000 Å. Superimposed on this continuum is a series of atomic lines, molecular bands and continua that are seen in absorption above 2000 Å, and in emission below about 1800 Å. Both emission and absorption features are seen in the 1800 to 2000 Å range. The strongest emission feature is the H-Lyman α resonance line at 1216 Å. Other prominent emission lines include the O I resonance triplet at 1302, 1304, and 1306 Å, the C II resonance doublet at 1334 and 1336 Å, and the C IV resonance doublet at 1548 and 1550 Å. The latter are of interest to the TRACE mission because they are formed at about 100,000K, which lies in the transition region between the solar chromosphere and the corona.

Figure 2 shows the region near the C IV lines in more detail. The C IV doublet, as well as the other prominent resonance lines are marked. The resolution of the SOLSTICE instrument, while not high enough to completely resolve the doublet, is adequate for evaluation of the contribution function of the

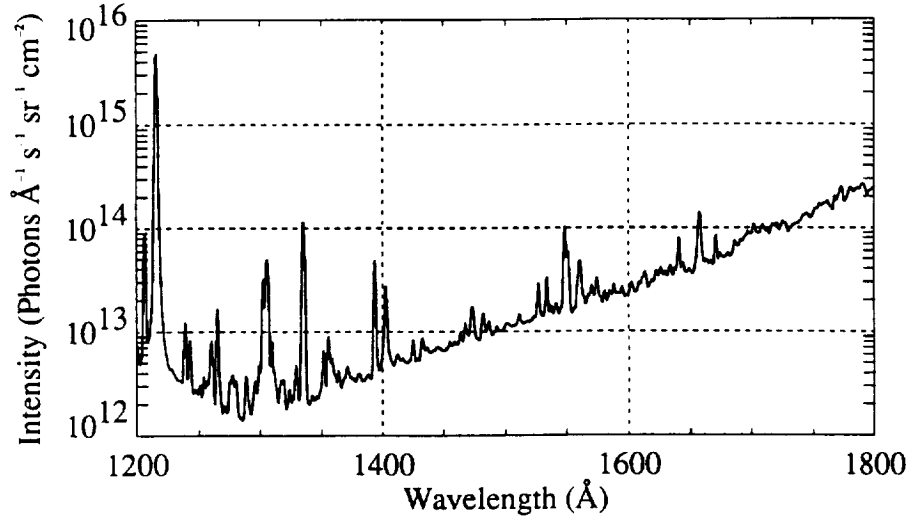


Figure 2: SOLSTICE spectrum, expanded in the vicinity of the C IV lines.

TRACE filtergrams. Note that the continuum level between the wavelengths of 1300 Å and about 1700 Å is well represented by a straight line, suggesting a power law dependence on wavelength. Note also that the wavelength region around 1600 Å is nearly free of strong emission lines. Bonnet et al. (1982) have interpreted narrow-band images recorded in this interval in terms of local temperature variations in the temperature minimum region.

3 TRACE Observing Approach

It is clear from the data of Figures 1 and 2 that the observation of the UV lines with filter technology places extreme demands on the filters. They must suppress visible and near UV radiation by six to eight orders of magnitude, while retaining a usable signal level in the desired bandpass. TRACE addresses the problem in several steps. First, is a metal-dielectric interference filter that excludes most of the visible radiation while transmitting in the ultraviolet. It provides about four decades of suppression at and above 4000 Å with respect to its design wavelength of 1400 Å. This filter also acts as an entrance window to the UV quadrant of the telescope to mitigate the effects of photopolymerization on the telescope mirrors and to control scattered light. Next is a multilayer dielectric coating on the telescope primary that is designed to have a high reflectivity only in a narrow band centered around the C IV lines. It provides an additional decade of suppression outside its designed bandwidth of about 250 Å. The UV quadrant of the secondary mirror carries a conventional Al / MgF₂ coating in order to retain some response to the H-Lyman α line. Finally, two to three additional decades of suppression are provided by the individual analysis filters, which are heavily blocked against visible and near-ultraviolet radiation. All filters and coatings for the UV quadrant are being manufactured by the Acton Research Corporation.

These measures are adequate to permit reasonably clean observations to be made in the H-Lyman-α line and in the UV continuum. The C IV observations, however, are more difficult due to tradeoffs in the narrowband interference filters. As the full-width at half-max (FWHM) of the filters becomes narrower, the

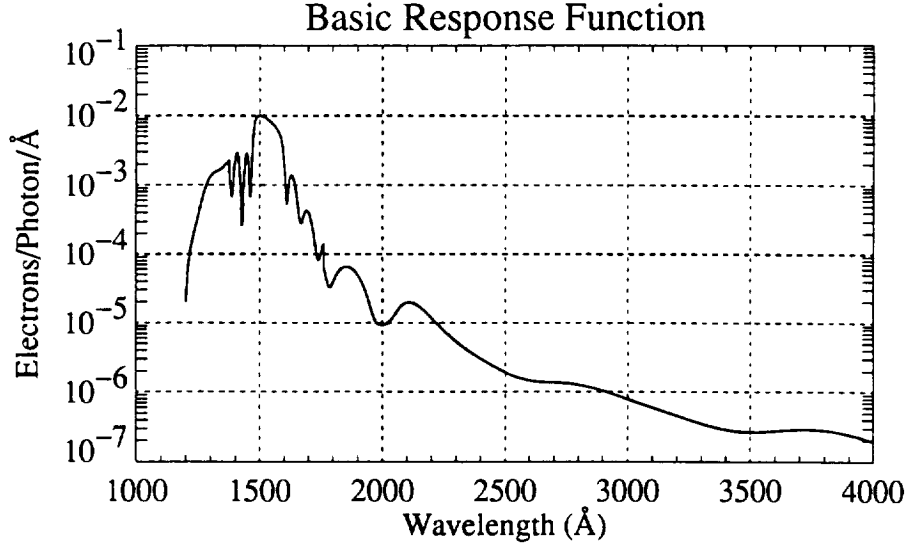


Figure 3: TRACE basic response function, including the effects of entrance window transmission, mirror reflectivities, and the lumigen-coated CCD.

out-of-bandpass transmission begins to grow unacceptably large, so a tradeoff between small FWHM and out-of-band rejection must be made. To address this problem, we use a procedure in which the unwanted contributions to the signal are separately evaluated and subtracted from the observed values. The remainder of this section will be devoted to a discussion of the C IV observations.

The combined effects of the entrance filter, the multilayer dielectric coating on the primary mirror, the secondary mirror coating, and the lumigen-sensitized CCD detector are shown in Figure 3. The response has a maximum at 1500 Å, and falls rapidly on both sides. The ripples in the response curve on either side of the maximum are due to secondary maxima in the reflectivity of the dielectric mirror coating. Although the response is substantially reduced at the wavelength of the H-Lyman- α line, the latter is so strong that observations can still be made.

The TRACE instrument carries a total of four UV transmitting filters, three of which are required for the C IV observations. Transmission curves for the latter are shown in Figure 4. The 1550 Å filter consists of one coating designed to produce a narrow “spike” plus other coatings that provide blocking of secondary maxima that are found at longer wavelengths. The TRACE filter wheel is also provided with a fused silica window that can be combined with the 1550 Å filter to suppress wavelengths below about 1700 Å while transmitting longer wavelengths with little attenuation. We use this combination to evaluate the contribution of the long-wavelength “leaks” in the 1550 Å filter. The transmission curve of the window + filter combination is shown by the dashed curve in the figure. Finally, a somewhat broader filter at 1600 Å is provided to evaluate the intensity of the UV continuum.

3.1 Contribution Functions

The relative contributions of the different parts of the solar spectrum to the signal level on an average CCD pixel may be estimated by folding together the spectrum of Figure 1, the basic response function of Figure 3 and each of the analysis filters. Results are given in Figure 5. The top curve corresponds to the 1600 Å

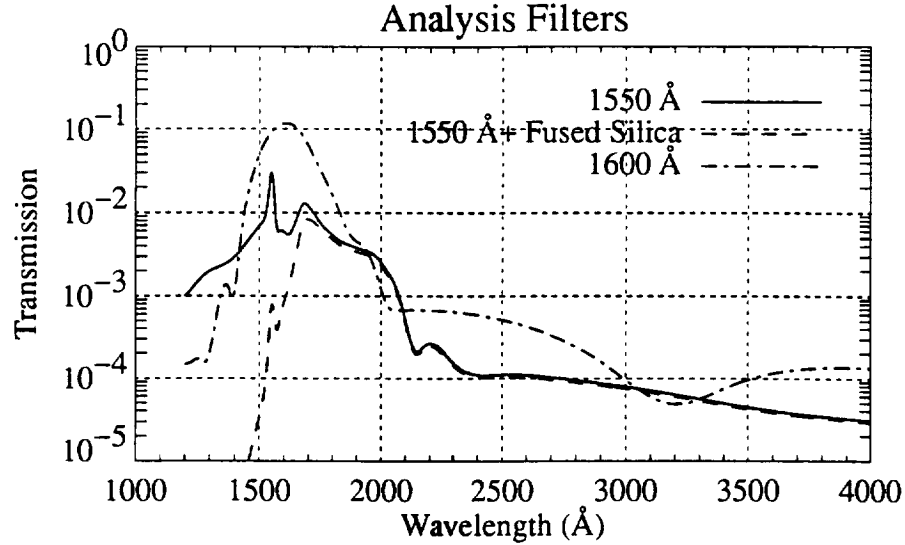


Figure 4: UV transmission of the filters used for determining the C IV intensity. The solid curve is for the narrow-band filter centered on the C IV lines. The dashed line shows the effect of adding a fused silica window to the C IV filter to evaluate the contribution of long wavelengths to the C IV signal. The broad filter at 1600 Å is used to evaluate the UV continuum intensity.

Å filter, the center to the 1550 Å filter and the bottom to the filter + silica window combination. Although the strongest contribution to the 1550 Å signal is from the C IV lines, it is clear that the continuum makes substantial contributions, even from wavelengths that are well outside of the 30 Å bandpass of the filter.

The magnitude of the non-C IV contributions may be readily evaluated by examining the running integral of the contribution function, shown in Figure 6. The continuum begins to contribute substantially to the signal at about 1470 Å, and reaches about 1/3 of the total at the onset of the rapid rise that represents the C IV doublet. C IV contributes about 1/3 of the signal, and the remainder is again, dominated by the continuum. When the integration is carried out using higher-resolution data (such as those from HRTS or UVSP), one can begin to see the effects of individual emission lines; some are visible in Figure 6. However, the continuum is the dominant contributor in all cases that we have studied.

3.2 TRACE Data Analysis Approach

To create an image dominated by the C IV lines, a TRACE observing sequence will include three images; one through the 1550 Å filter, one through the filter + window combination, and one through the 1600 Å filter. The first stage in analysis is to verify the coalignment of the images using a cross-correlation technique. Since the TRACE fine-guidance system stabilizes the image positions to about 0.1 arcsec, coalignment corrections are expected to be small.

The second step in the analysis is to correct the 'filter + window' image for reflection losses at the window and subtract it from the 1550 Å image. This step effectively eliminates the contributions due to long wavelength "leaks".

The next step is to evaluate the broadband contributions from the UV continuum and unresolved weak lines, using the data from the 1600 Å image. This is scaled and subtracted from the intermediate result

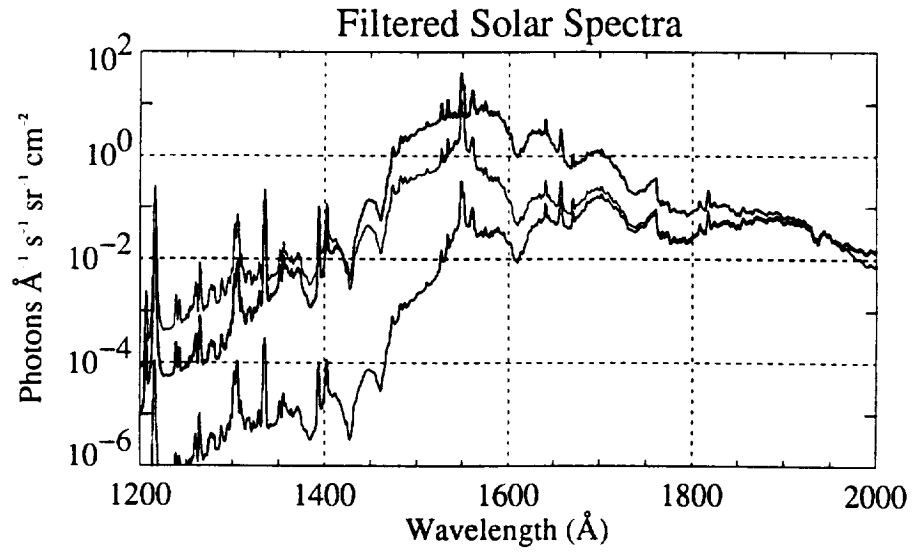


Figure 5: TRACE contribution functions; responses to the solar spectrum with the analysis filters in place. The top curve corresponds to the 1600 Å filter, the center curve to the 1550 Å filter, and the bottom to the combination of the 1550 Å filter with the fused silica window.

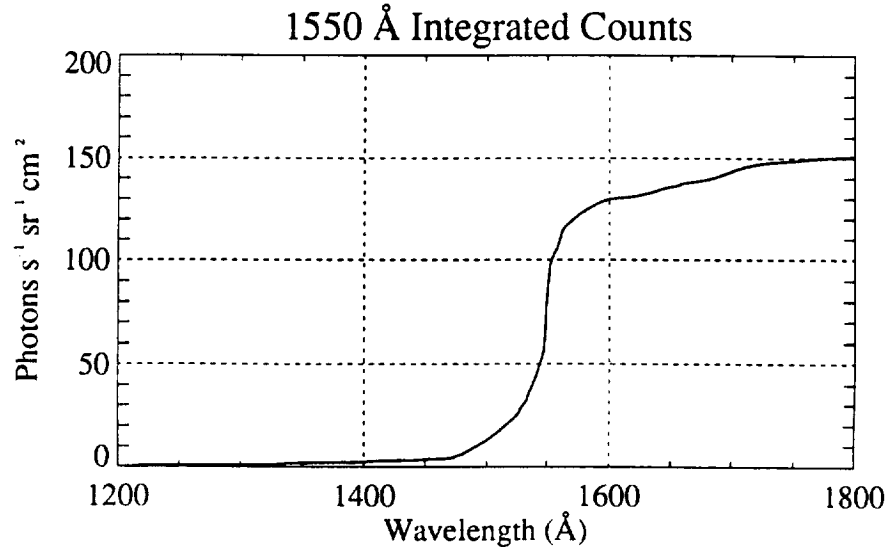


Figure 6: TRACE response to the solar spectrum with the 1550 Å analysis filter in place. This curve represents the running integral of the contribution function of Figure 5.

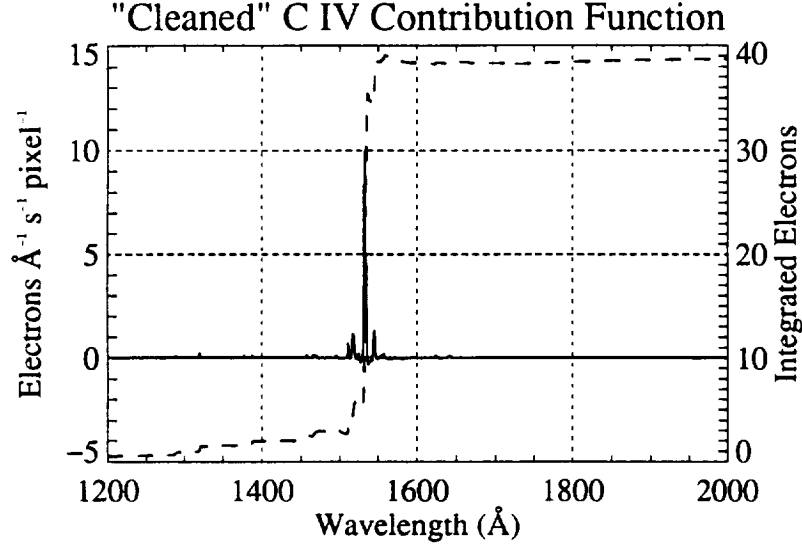


Figure 7: The solid curve is the effective 1550 Å contribution function after correcting for the effects of long wavelength “leaks” and the UV continuum. The running integral of the contribution function (dashed curve) shows that the C IV lines now contribute the majority of the remaining signal.

to produce the final “cleaned” C IV image. Figure 7 shows the contribution function for an average pixel, where the scaling factor has been computed on the basis of the SOLSTICE spectrum. Both differential and integral forms of the function are shown. The C IV lines now contribute about 80% of the observed signal; most of the remainder is due to lines from Si II and C I which are formed in the chromosphere. The ratio will obviously vary from point to point on the sun depending on the level of activity. Intensities in the cleaned images will be most accurate in active regions and at the limb, and will be least reliable in the interiors of supergranulation cells.

The determination of the scaling factor used in the final cleaning step has the greatest level of uncertainty at this stage of our preparations. Our original intent was to infer a local temperature map from the 1600 Å data, following the method of Bonnet et al. and then to compute the continuum contribution to the 1550 Å filter on the basis of the Planck function. The UV spectrum, however, doesn’t conform well to a black body spectrum so it became necessary to explore this in more detail. The UV spectrum from ~ 1300 Å to 1800 Å is more closely represented by a simple exponential as a function of wavelength. This is allowed to vary as a linear function of the intensity in the 1600 Å filter.

$$I_{\text{synthetic}}(\lambda, I_{1600}) = (A + B \times I_{1600}) \times \exp(C \times \lambda) \quad (1)$$

Understanding the error bound associated with this technique is a difficult problem. It is a simple matter to make a simple error analysis based on counting statistics, but the greatest error is due to errors in the model itself. Without a priori knowledge of the input spectrum it is unclear as to how to estimate the systematic errors in the model. Furthermore, as we wish to isolate only the 1548 and 1550 Å lines, all other emission lines in that region add to the error. Studies with a more comprehensive set of spectra over a variety of extremes will be required in the time remaining before TRACE launch.

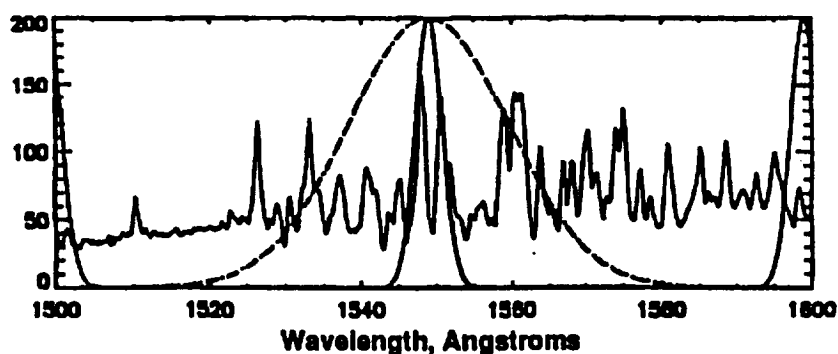


Figure 8: Use of a Fabry-Perot etalon to isolate the C IV lines. The figure shows a typical scan of the 1500 – 1600 Å region of the solar spectrum together with the transmission curve of a narrow-band filter (dashed curve) and three orders of a Fabry-Perot etalon with a finesse of 10. The dashed curve is representative of the performance of the TRACE 1550 Å filter, which has a bandpass of about 30 Å.

4 Tunable UV Etalons

The discussions in Section 3 illustrate the difficulty in observing all but the brightest UV emission lines with existing filter technology. The narrowest available UV interference filters have bandwidths of order 20–30 Å at 1550 Å. These filters are essentially multi-cavity solid etalons that are created by a vapor deposition process. Their performance is limited both by the availability of suitable materials, and by the uniformity and accuracy of the deposition process. The lack of UV transmitting materials with a wide range of refractive index is especially troublesome.

The use of vacuum-spaced Fabry-Perot etalons appears to be a promising solution to these problems. Use of a vacuum spacer effectively increases the total range of refraction indices available to the designer, enabling them to concentrate on optimization of the coatings that create the cavity. A finesse of 10 appears to be achievable at 1550 Å with current polishing and coating techniques. In addition, one now has the option of tuning the cavity by varying the spacing of the interferometer plates with piezoelectric transducers.

The principle is illustrated in Figure 8, which shows a portion of the spectrum surrounding the C IV lines together with the transmission curves of the TRACE 1550 Å filter and an etalon with a finesse of 10. The width of the etalon cavity has been chosen such that orders are separated by 50 Å and only one order falls within the bandpass of the 1550 Å filter. The bandwidth of each order is 5 Å (FWHM); adequate to isolate the C IV doublet from the other nearby chromospheric lines. The predicted finesse of this etalon is above 8 throughout the 1520 – 1580 Å spectral range. By tuning the etalon and interchanging interference filters, it would be possible to observe at any wavelength in the interval.

An etalon of this design has been under development at Lockheed Martin during the past several years, and a prototype now exists. Material for the plates is cultured quartz, grown by Sawyers. The plates, housing, and piezoelectric transducers were produced for us by Queensgate, Ltd. of England. The polished etalon plates were coated by Acton Research Corp. and then returned to Queensgate for final assembly. All work on the Queensgate etalon was funded under the Lockheed Independent Development Program.

Results of an early test of the etalon at wavelengths near 1600 Å are shown in Figure 9. The figure shows three orders of interference as the etalon is tuned while being illuminated by a fixed wavelength. The

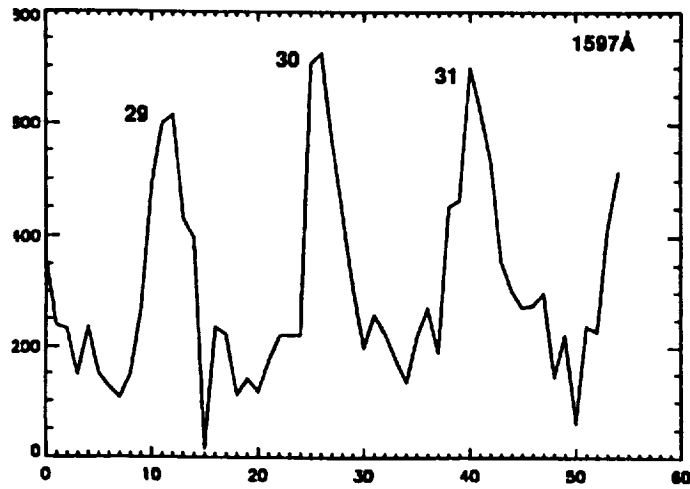


Figure 9: Early performance demonstration of the Lockheed Martin UV Etalon. Three orders of interference are revealed as the etalon spacing is scanned while viewing a constant wavelength of 1597 Å.

Wavelength (Å)	Predicted Finesse	Maximum Transmission
1210	4.9	4.74 %
1300	5.8	2.84 %
1350	6.4	8.38 %
1450	14.7	39.1 %
1550	34.2	36.5 %

Table 1: Initial results from a theoretical study of Fabry-Perot etalon performance.

measured finesse was in the range of 4 to 5. This is in reasonable agreement with the predicted value of 6 at this wavelength, since the test was carried out in a slightly diverging beam. Impurities in the crystal from which the etalon plates were made produced strong absorption in the 1550 Å range that have so far, prevented us from testing the unit at its design wavelength.

Current work on etalon development is being funded under the NASA Supporting Research and Technology Program. Our goal is to investigate etalon designs at shorter wavelengths, and to establish the practical short-wavelength limit. One of us (Zukic) has been involved in the design of vacuum ultraviolet coatings for many years, and has investigated the theoretical performance of etalons using these coatings in the 1210 – 1550 Å wavelength range. The results are very encouraging. Predicted finesse can be as high as 34 at 1550 Å and it appears possible to design etalon coatings that will work at H-Lyman α with a finesse of nearly 5.

Figure 10 shows the computed properties of a mirror coating optimized for a Fabry-Perot etalon operating at 1450 Å. The peak reflectivity is nearly 90 % and the absorptance is below 4 %. Figure 11 shows the predicted performance of an etalon using this coating. Two curves are shown, corresponding to two different cavity lengths. The predicted finesse in each case is 14.7. The same mirror coating also performs well at 1550 Å with a predicted finesse of 17.1. The predicted performances of several other designs are summarized in Table 1.

In the coming months, we plan to begin fabrication of test coatings of these designs, and are optimistic

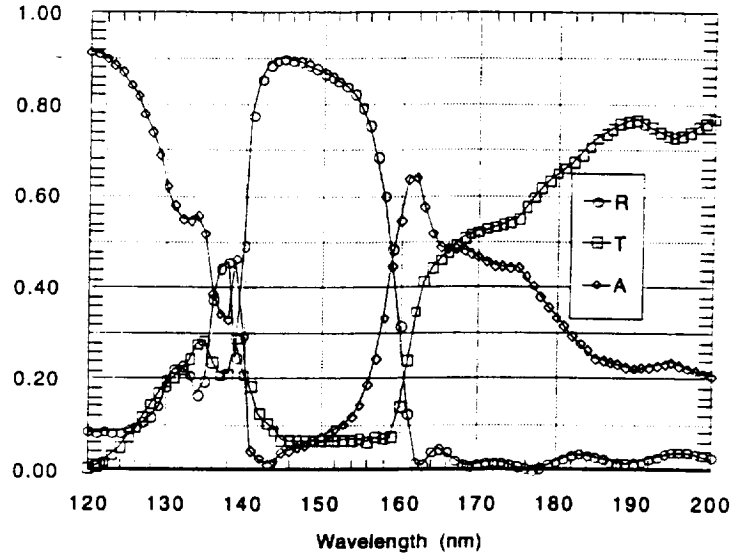


Figure 10: Reflectance, transmittance and absorptance of a multilayer optimized for use in a Fabry-Perot etalon operating in the 1450 Å range. At the design wavelength, the multilayer has a peak reflectance of 89.9 %, a transmittance of 6.3 % and an absorptance of 3.8 %.

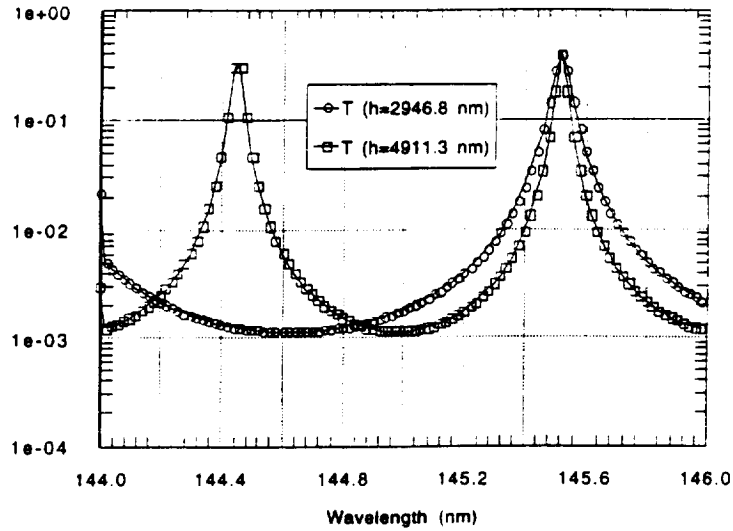


Figure 11: Predicted performance of a Fabry-Perot etalon using the multilayer coatings designed for 1450 Å. The two curves correspond to different vacuum gap thicknesses, as shown on the plot. A finesse of 14.7 and a maximum transmission of 39.1% are realized in each case.

about the prospects for the future of tunable etalons operating in the vacuum ultraviolet.

5 Conclusions

We summarize this work with the following comments: Images taken in UV lines are diagnostically useful, but are difficult to make with current filter technology. The major contaminant to the raw C IV images expected from the TRACE experiment turned out to be the UV continuum, rather than the strong chromospheric lines at nearby wavelengths as we had previously believed. However, this conclusion must be viewed with caution in view of the limited spectral resolution of the data used for the study. A substantial portion of what we see as continuum may arise from a collection of many weak, unresolved emission lines.

Tunable UV etalons show a great deal of promise in overcoming the limitations of currently available narrow band UV filters. Bandwidths of of 5 Å or less are clearly feasible. Tunability of vacuum-spaced Fabry-Perot etalons facilitates evaluation of the UV continuum level. The technology appears promising for wavelengths as short as 1216 Å (i.e. the H-Lyman α resonance line).

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References

- Bonnet, R. M. et al., 1982, *Astr. Ap.*, **111**, 125.
- Tarbell, T. D. et al., 1996 This Conference, [Paper 2804-24].
- Tousey, R., 1963, *Space Science Rev.*, **2**, 3.
- Strong, K. T. et al. *Space Sci. Rev.*, **70**, 119, 1994.
- Rottman, G. 1996, Private Communication.

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